MICROWAVE BAKING OF YEAST RAISED DOUGHS

by

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INTRODUCTION

Yeast raised doughs are normally baked by conventional heating where radiation and convection heat penetrate from the surface of the dough into the interior (1). This process sets up a temperature gradient with uneven heating of the dough mass and requires time for penetration and baking of the interior of the dough piece.

Microwave energy is a high frequency alternating electrical force that causes molecular excitation in the dough (1). This excitation, which is in the form of high frequency oscillation of the molecules, produces heat internally in the dough. Not all substances are susceptible to microwave molecular excitation, but water and lipid molecules are very susceptible. Dough, which is high in moisture content and also contains fat, is readily heated by microwave energy. Since microwave heating is in the form of molecular excitation, it has little tendency to create heat gradients (1). Therefore, if the exposure to microwave energy is constant throughout the dough piece, then the temperature throughout the dough piece will be uniform. Since microwave energy is evenly distributed, the surface temperature of the dough is not high enough to promote browning and form a crust.

Microwave energy, with its unique heating capability, shows definite potential for its application in the baking in-

dustry. Microwave energy was first suggested for use in the baking industry in 1947 by Cathcart et al. as a means of reducing mold spore contamination in bread (2). Microwave energy has been successfully applied in proofing of yeast raised doughnuts and has reduced the proofing time of 25-30 minutes down to an average of 4 minutes (3,4). Microwave energy has also been used in combination with deep fat frying of doughnuts to reduce frying time and increase doughnut volumes (3). Bread baking has been carried out using a combination of conventional and microwave heating (5,6,7). This application has not yet been applied in the industry, due to various economic and production problems. Microwave energy has been applied commercially for moisture reduction in the production of biscuits (1,8). Defrosting of frozen bakery products and ingredients has also been investigated (1,8,9).

The primary purpose of this study was to develop a yeast raised bun by use of a combination of microwave and conventional baking procedures that is equal in quality to a conventionally baked bun. A second objective was to investigate the effect of various ingredients and processing steps on production of a combined microwave and conventional bake procedure as compared to the conventional procedure. This research was performed with a hope that information gained from this study would increase the understanding of possible applications of microwave baking to any yeast raised baked products.

LITERATURE REVIEW

Microwave Heating

Microwaves are electromagnetic waves of radiant energy which differ from other forms of electromagnetic waves such as light waves, radio waves and X-ray waves primarily by wavelength and frequency (10). Microwave energy has frequencies in the range of 400 to 20,000 megacycles per second and has wavelengths in the range of 1 to 30 inches (10). Since some microwave frequencies are close to those of radar and radio waves, the Federal Communications Commission has designated specific frequencies for specific uses. The microwave frequencies that are approved for use in the food industry are 2450 ± 50 megacycles per second and 915 ± 25 megacycles per second (4) of which 2450 megacycles per second is most widely used in the United States.

Microwaves, like all forms of electromagnetic radiation, travel in straight lines. They are reflected by metals; transmitted by materials such as glass, air, paper and plasti ; but are absorbed by materials such as water and fat, which are normal food constituents (10). The degree to which the microwave energy is absorbed determines the amount of heat produced. Heating efficiencies are greatly influenced by the composition of the food (10). Microwave energy is a function of frequency and is governed by the relationship:

$$\text{Energy} = hf$$

where f = frequency and h= Plank's constant ($6.625X10^{-2}$erg sec) (11,12). Therefore, higher frequency microwaves are absorbed more quickly by absorbant materials and generate more energy in the form of heat. A lower frequency microwave has the ability to penetrate deeper into the food product. For example a 900 megacycle microwave can penetrate in water 6 times as far as a 2450 megacycle microwave before half of its incident energy is lost (10).

Microwave energy, when absorbed by water or fat molecules, causes molecular oscillation and intermolecular friction which creates heat in the dough (10). This phenomenon is the result of the dipolar molecules, such as water, attempting to align themselves with an alternating electromagnetic field which is alternating at, say, 2450 million times per second in a typical microwave oven (4). When the molecules are aligned with the electromagnetic field they gain potential energy that will be released in the form of heat upon relaxation of the field (4). Since there is a very large number of dipolar molecules in dough, and since each of these molecules is attempting to realign with the alternating electromagnetic field at a very high rate, the dough mass generates a very significant amount of heat.

Several unique properties of microwave energy that must be considered in applying microwave energy to the heating of

food were outlined by Sale (13):

(a) Microwaves generate heat directly within the food. Heat conduction is not involved, except as a secondary effect of uneven heating.

(b) Microwaves raise food temperature rapidly.

(c) Microwaves cannot penetrate metal. This condition limits the materials in which a dough can be baked. It is also an important property in designing equipment to contain and control microwaves.

(d) Microwaves readily pass through materials such as glass, polypropylene, and paper. This is an important consideration in choice of containers and packaging materials for baked products when baking doughs or sterilizing final products for mold control.

(e) With microwave heating temperture rises are not limited by the temperature of the heat transfer medium as with conventional heating methods.

(f) Both wet and dry foods can be heated by microwaves but wet foods are heated more efficiently.

(g) The geometry of the food effects how evenly heat is generated in the food.

(h) In thawing of foods with microwaves thermal runaway can occur. This is caused by the fact that water in a frozen state absorbs microwave energy less readily than water molecules in a fluid state. The areas to thaw first can be heated much

faster than unthawed areas.

There are several other important considerations not covered by Sale:

(a) Microwave energy does not heat the air around the cooking product, except indirectly through conduction heat given off by the product itself (4).

(b) Microwaves not only pass through materials such as glass, paper, and polypropylene, but they do not heat these materials in the process.

(c) Microwave energy does not produce heat gradients as is the case with conventional heating.

(d) Heating is instantaneous without oven warm up as is required in conventional ovens (4).

(e) Depth of penetration varies with frequency. However, frequencies assigned for food use provide adequate penetration for uniform heating in most bakery applications (4).

(f) Microwave heating, due to its uniform heating throughout, does not allow surface temperatures high enough to promote browning (10).

A microwave oven, as described by Potter (10), is a metal cabinet into which an electromagnetic generator called a magnetron is inserted. A magnetron is an electron tube that generates high frequency radiant energy. Its power output is rated in Kilowatts. The cabinet normally contains a metal fan for distributing the microwaves, which are reflected off

the microwave walls repeatedly until absorbed by the food. The food is normally placed on a shelf of glass or other microwave transmitting material, so that it receives microwaves from all directions allowing even distribution of microwave absorption.

Conventional Heating and Browning

In conventional baking the oven transmits heat to the dough surface by radiant, convection, and conduction, with the distribution of these heat forms dependent on the oven design (14). This heat is gradually transferred into the interior of the loaf by conduction (11). This gradual transfer of heat sets up a temperature gradient within the dough piece. The internal portion of the dough cannot reach a temperature above 100°C as long as there is free water available to form steam (10). However, the surface of the dough does dehydrate and reaches temperatures much higher than 100°C, allowing browning and crust formation to occur.

Browning involves two reactions, caramelization and the Maillard reaction. Caramelization is the conversion of sugar into colored substances through initial hydrolysis of monosaccharides and then subsequent polymerization (15). The Maillard reaction normally utilizes free amino acids and free reducing sugars which are condensed to form an N-substituted glucosylamine, which, then goes through an isomerization

reaction to form 1-amino-1-deoxy-2-ketoses (15). These compounds undergo dehydration to form various products depending upon the starting amino acids and sugars and the reaction conditions (15). These reactions produce the brown crust and characteristic flavors associated with the conventionally baked yeast-raised product.

Microwave Applications to the Baking of Yeast-Raised Products

Microwave energy was first applied to yeast-raised bakery goods as early as 1947 as a means of inhibiting mold growth (2). Olsen (16) found that treating bread after slicing by microwaves until internal temperatures of 145-150°F were reached was more effective than calcium propionate as a means of reducing the growth of contaminating fungi on bread. Olsen (16) also reported that the temperatures necessary to kill specific mold types were greater with conventional thermal heat than with microwave heat, indicating that the mold spores may present a preferential target for microwave heating.

Microwaves have been used successfully in the doughnut industry to greatly reduce proof times. Schiffman et al. (17) state that proofing of yeast-raised doughnuts serves several functions, all of which are heat dependent. These functions are generation of leavening gases, development of gluten structure, evolution of flavor, and formation of shape-retaining skins for doughnuts. Conventional systems depend upon

conductive heat to raise the dough temperature, and only a small temperature differential between dough and proofing environment can be tolerated to prevent excessive heating of the dough surface. Consequently, conventional proofing methods require 25-35 minutes to undergo proofing (17). Since microwaves heat the dough rapidly and uniformly through internal heating, the dough can be raised to final proofing temperatures in a few seconds, allowing total proofing time to be reduced to as short as 4 minutes (17). This very short proofing time puts severe demands on the dough which requires special formulations (4).

Microwave baking of pan breads has not been adopted commercially by the baking industry. Only a few general reports have been published about producing breads by a combination of microwave and conventional baking processes. Fetty (5) reported that both rolls and one pound loaves of bread could be produced by microwave baking a conventionally produced bread dough. The dough was partially baked in a 10 KW power microwave unit for 2 minutes with a 200 pound per hour throughput. The optimum maximum crumb temperature was found to be 190°F to set up the cellular structure. Optimum proof time before microwave partial baking was reported to be 30 minutes. This reduction was thought to be due to the absence of crust formation which restricts dough expansion during baking. Fetty (5) stated that the product could be used at this stage as a

partially baked roll such as brown and serve rolls, or it could be browned in a conventional oven. The microwave products were reported to have reduced bakeout loss, increased yeasty fermentation flavor, and a highly desirable eating quality. Decareau (9) also reported the production of partially baked bread by reducing proof time and baking as little as 3 minutes in microwave oven. Product volume and texture were claimed to be equal to conventionally produced partially baked products. The lower ambient temperatures in baking with microwaves were thought to improve flavor retention. Shute (8) reported that microwave energy at 2450 MHz frequency lacks adequate penetration for a standard size loaf of bread and suggested the use of 900 MHz for larger sized products.

The Flour Milling and Baking Research Association at Chorleywood (6,7) has utilized microwave-thermal baking as a way to overcome the excessive amylase activity of many English wheat flours. The rapid baking achieved with microwave-thermal heating significantly reduces the time for amylases to act upon starch. This would increase the amount of English flours that could be blended with stronger flours for bread production without excessive loss of volume as is experienced with the conventional baking process. They have also found that lower frequencies around 900 MHz gave superior results with 1 3/4 lb. white pan bread, and that simultaneous application

of microwave and thermal energy was more successful in achieving normal appearance and stability than either thermal heating before or after microwave treatment. With the simultaneous heating, thermal temperatures as high as 600°F for 8 minutes were required.

Lorenz et al. (18) baked microwave breads and rolls using relatively dark doughs such as rye, wholewheat, and Boston brown breads which would require little if any thermal baking to obtain an appealing crust color. They found that microwave baking required a reduction in fermentation time and proof time to obtain optimum results. Microwave baking of 900 gram wholewheat loaves yielded the best texture with a 7 minute bake, but the loaf settled reducing the volume. A 10 minute bake produced the best volume, appearance, symmetry, and grain. Rye bread quality was best with a 9 minute bake time. Brown and serve rolls were found to have an optimum bake time of 45 seconds. Microwave baked bread was slightly softer in texture than the conventional baked bread and had 2-2.5% higher moisture content. Sensory evaluation showed microwave baked wholewheat bread to be less favorable in both texture and flavor and microwave baked rye bread to be less favorable in texture but equal in flavor to conventional controls. Microwave baking of brown and serve rolls produced a quality product, and the microwave baking permited elimination of the use of mold inhibiters in the formulation.

Microwaves are not capable, in normal food cooking situations, of breaking chemical bonds (12). Therefore, nutrient losses would not be expected, except due to thermal destruction which is apparent with any cooking system. This is supported by Goldblith et al. (19), who tested thiamine (vitamin B_1) at temperatures from 0 to 102.8°C and found that thermal destruction accounted for all losses of the vitamin. He also reported that microwave irradiation for extended periods at lower temperatures caused no destruction of thiamine.

Fetty (5) reported that the stability of the enrichment additives was not affected by microwave baking. Tsen et al. (20) found that rats fed microwave bread had better protein efficiency ratios and better feed conversion ratios than those fed a conventionally baked control. This was thought to be due to increased crumb and crust browning with conventionally baked bread, since lysine availability is thought to be reduced during the browning reaction.

Microwave energy has also been used for thawing bakery products which were baked at a central plant and shipped in a frozen state to retail locations (8). There is also potential application in frozen dough operations for utilizing microwave energy to increase thawing rate as well as in accelerating proofing and baking.

Surfactants

Surfactants serve a number of functions in food systems (21): They function in improving solubilization, in influencing

crystal modification, and in complexing functions as dough improvers. In the complex dough system, surfactants may serve several or all of the above listed functions. As a dough improver, a surfactant is used in production of yeast raised products to improve shelf life, to increase mixing tolerance, to increase dough strength, to increase volume, and to improve crumb texture and cell structure (22). A surfactant is a polar compound. Different parts of the emulsifier are soluble in different solvents, usually immiscible solvents such as oil and water (22). This ability to interact with two different solvent phases gives the surfactant unique properties to influence the physical or chemical characteristics of the two phases. This unique ability is the result of the surfactant possessing both hydrophobic and hydrophilic functional groups (23). The hydrophobic group is usually a hydrocarbon group and the hydrophilic group can be either an ionic or polar non-ionic group (23).

Sodium stearoyl-2-lactylate (SSL) is anionic and hydrophilic in nature (21). It is the reaction product of stearic acid and lactic acid, neutralized by a sodium salt to form a sodium salt of stearoyl-2-lactylic acid (15). It occurs as a homologous series of stearoyl lactylic acids where the number of lactylic groups averages 2 (24). It improves loaf volume, inhibits crumb firming or staling, and produces good bread quality (21). SSL also improves mixing stability and tolerance (25) and de-

creases water absorption slightly (26). It is thought to suppress lipid binding during dough formation by partially replacing the lipid in the dough and promoting association of starch, lipids, and proteins (26). SSL was found to displace some glycolipids and to enchance polar lipid binding in starch-lipid-protein complexes (27). In sponge and dough procedures SSL does not become strongly bound to the protein fraction until dough mixing of the dough stage (28). As temperature is increased during baking protein is denatured and the bonds between protein molecules and SSL are weakened. As the starch gelatinizes the SSL readily forms a strong complex with the starch molecules (28).

Ethoxylated monoglycerides (EMG) are a nonionic, hydrophilic emulsifier (21) that is formed by reacting monoglycerides with ethylene oxide at a ratio of 20 moles of ethylene oxide to 1 mole of the monoglyceride (15). EMG is reported to improve grain, to increase volume, to retard rate of crumb firming, and to improve resistance of proofed loaf to adverse handling (29,15). However, EMG has only small improving effect on staling (21). EMG, as SSL, improves dough stability and decreases water absorption (26). Optimum dough stability was found at the 0.5% EMG level, while with SSL dough stability was positively coorelated with surfactant level. This is thought to indicate a possible difference in dough improving mechanism between ionic and nonionic surfactants (26). EMG is

thought to compete with lipids for binding sites and suppresses lipid binding to an even greater extent than SSL (26). EMG has less binding capability than SSL, and it is significantly less involved in linking proteins to starch than is SSL (26). Unlike SSL, EMG was found to displace phospholipids, to reduce binding of polar lipids in the protein-lipid-starch fraction and to enchance binding of glycolipids and phospholipids to acetic acid soluble proteins (27). EMG also has weaker complexing effects than SSL (30).

Polyoxythylene (20) sorbitan monostearate (Polysorbate 60) is a nonionic, hydrophilic emulsifier with a hydrophilic moiety, (21). It is formed by esterifying propylene glycol with stearic acid to form sorbitan monostearate, which is reacted further with ethylene oxide at a given mole ratio to form an average polyethylene chain length of 20 (15). It can improve a dough's resistance to adverse handling conditions following proof, it can increase volumes, and can improve grain and crumb characteristies (15,21). Polysorbate 60, like EMG, has only a small improving effect on reducing rate of staling (21,31). Polysorbate 60 can increase farinograph absorption. This is thought to be due to a binding of water by hydrophilic groups of the polysorbate (31). Ninety minutes extensograph studies showed that Polysorbate 60 reduced extensibility and increased resistance to extension (31). Amylograph studies showed that Polysorbate 60 increased both hot and cold paste

viscosities (31). Little work has been published on the mechanism of polysorbate's affect as a dough improver, but since it, like EMG, is a non-ionic surfactant, the characteristics of lipid, protein and starch interactions found with EMG may explain, at least to some degree, the action of Polysorbate 60.

Succinylated monoglyceride (SMG) is an anionic and hydrophilic compound formed by reaction of equimolar quantities of glycerol monostearate and succinic acid (15). It functions as a staling inhibiter, it improves grain and texture, it strengthens gluten structure, it improves loaf volume, and it improves resistance of dough to mechanical abuse after proofing (15,21). SMG also has been reported as an excellent dough improver in buns, even with relatively weak flours (32). As with SSL, SMG did not associate to any degree during the sponge stage of the sponge and dough process, but it did form a strong bond with flour proteins during dough mixing (28). The strength of binding of SMG increased with gluten formation during mixing to optimum, but it decreased when dough was overmixed (28). The degree of SMG-protein binding is less for SMG than it is for SSL. Very little complexing of starch and SMG was found until temperatures above 50°C were reached (28).

During baking the bonds between SMG and protein molecules became increasingly weaker (28). SMG was much more readily released by gluten when heated than was SSL (28).

Response Surface Methodology

Response surface methodology (RSM) was first developed by Box and Wilson (33) to determine optimum conditions for chemical investigations. A comprehensive discussion of the principles behind RSM was given by Davies (34), and basic experimental designs for use of RSM in optimizing experiments were outlined by Cochran and Cox (35). Myers (36) gave a thorough presentation on both theory and modern application of RSM.

RSM is an experimental design technique used to find the levels of various factors that give an optimum response. The response n is defined by a mathematical model $n = \beta(X_1, X_2 \cdots X_k)$, where the X-values are the independent variables and β is the response function (34). The independent variables represent the levels of the factors that are to be varied experimentally. The responses found experimentally for preselected X-values generate a least squares estimate of β, which can then be used to construct a response surface of the predicted values of $n = X\hat{\beta}$ as a function of the X's (37). Through plotting this response surface three-dimensionally or through search procedures, if the number of independent variables is large, the experimenter can determine the levels of the independent variables that give the optimum responses.

A number of food industry applications of RSM for ingredient formulation optimization and production conditions optimization have been reported (38,39,40).

Snee (41) discussed methods for design and analysis of mixture experiments where the sum of the proportions of all independent variables in the mixture must equal a pre-established constant. A mathematical model for a response surface can be determined and analysis performed in much the same manner as RSM. Careful interpretation of the coeffecients (β_i) in the model can yield information as to the relative contribution of the different independent variables, both singularly and in combination (41).

MATERIALS AND METHODS

Flour Data

Two hard red winter wheat flours were used, both of which were milled in the KSU experimental mill. They were bleached, enriched, and malted. The KSU flour is a relatively weak low protein flour and the KSU Hipro flour is a relatively strong high protein flour. The vital wheat gluten was supplied by Midwest Solvents Co. Analyses of flours and vital wheat gluten are given in Table I.

Farinograms

Farinograph tests were performed, using constant flour weight, according to AACC method 54-21 (42). Water absorption was adjusted to obtain maximum consistency at 500 Brabender Units (B.U.). Farinograms with addition of surfactants were made with the same water absorption as the control KSU Hipro flour. Flours were adjusted to 14% moisture basis. Surfactants were dissolved in 30 ml of 55°C water before addition to farinograph, and the 30 ml of water was deducted from the total water added to achieve the absorption of the control.

Baking Tests

The K-State (Kansas State University) process for making breads (43) as was modified by Tsen et al. (44) was used as a basic procedure for producing buns. This procedure was modified by deleting the use of soy protein. Formulation and procedures

Table 1. Analyses of Flours and Vital Wheat Gluten

Flour	Protein[a] %	Moisture %	Farinograph absorption %	Farinograph mixing time min.
KSU	10.5	13.8	56.2	2.0
KSU Hipro	12.3	13.0	59.8	22.0
Vital Wheat Gluten	71.4	7.9	-	-

[a] Protein factor: N X 5.7

were varied as will be outlined in the Experimental Results section. Vital wheat gluten when used was added as a replacement for an equal weight of the total flour. The basic baking formula included:

Ingredient	Weight (gms.)	% of Total Flour
Flour	150.0	100
Sugar	18.0	12.0
Salt	3.0	2.0
Shortening	3.0	2.0
Yeast	6.0	4.0
$KBrO_3$	Variable	-
Water	Variable	-
Gluten	Variable	-
Surfactants	Variable	-

All ingredients were combined at room temperature and mixed in a National Mixer with 325 gram flour capacity. Mixing times are outlined in the Results and Discussion section. By varying water temperature, dough temperatures were controled between 84-86°F. The dough piece was rounded, placed in a container, and fermented for a specified time at 86°F and 85% relative humidity. Then the dough was scaled into four 50 gram dough pieces, rounded, and allowed to rest 10 minutes at 86°F and 85% relative humidity. The dough pieces were then molded into hot dog bun shape, placed on a silicone papered pan, and proofed for a specified period of time at 96°F and 95% relative humidity. Conventional controls were baked at 400°F for 12 minutes. Microwave-Conventional bake procedures were varied and will be outlined in the Results and Discussion section.

Microwave baking was done in a Montgomery Ward Model 8098 Household Microwave oven with an output of 650W and a frequency of 2450 MHz. All baking was done at the normal cook setting. Conventional baking and conventional browning of microwave baked buns were done in a Despatch reel oven. For high temperature browning of microwave baked buns the oven shelves were covered with a 1/4 inch thick asbestos sheet on top of which was placed an 1/8 inch steel plate. This procedure reduced excess browning of the bottom of the bun that is experienced when using only the steel plate. Use of the steel plate is necessary to achieve rapid high temperature surface browning on the bottom of the bun.

The conventional browning procedure involves placing the pan of four proofed dough pieces, which may or may not have been prebaked in the microwave oven, on the steel and asbestos lined shelf, and removing the pan while the dough pieces on a silicone paper lining are held in place on the oven shelf. Removal is done by merely sliding pan from under the paper liner. Microwave baking may be performed before or after conventional browning. The four dough pieces on the paper liner are gently slid off the pan into the microwave oven. Removal of the pan is necessary since the presence of the metal would prevent even distribution of microwave energy in the oven, as metals reflect microwaves (13).

Measurement of Baking Responses

Loaf weight, expressed in grams, and volume in cubic centimeters as determined by seed displacement, were measured between 30 and 60 minutes after baking. In microwave baking measurement of volume before 20 minutes of cooling caused some crushing of crust. This minimum cooling time was necessary to allow crumb to cool and firm to help support the weight of the seeds during the volume measurements. Volumes were taken on three buns simultaneously and specific volumes represent an average for three buns.

Grain was scored approximately 24 hours after baking on a scale of 1-10. Any score less than 6 is unsatisfactory. This is an arbitrary score done by comparing each bun with preserved representative buns of different grain quality and assigned scores. Using preserved standard buns allows comparison of grains of different experiments.

Compressibility measurements were made at 24±1 hours, 48±2 hours, and 72±2 hours from the time of baking. Compressibility measurements for surfactant series were done at 24±1 hours, 72±2 hours, and 120±2 hours. The compressibility measurements were done by placing a 3 centimeter thick cross section of the bun on a load cell which, through a dual strain gage amplifier and a strip-chart recorder, records the force exerted while compressing the crumb. The crumb was compressed by a cylinder 1.0 centimeter in diameter to a depth of 4 millimeters over a period

of 4.0 seconds. The strain gage amplifier is calibrated so that 100 units or the maximum value on the scale is equivalent to a force of 310 ± 5 grams, and each ten units is equal to 31 grams. Two measurements were taken from different slices of each bun and the average value recorded.

Total scores were computed on a basis of a maximum of 10 points for specific volume, 10 points for compressibility at one day, 10 points for compressibility at 3 days, and 10 points for grain. An arbitrary scale was established for each of the four measured responses, and then each measurement was given a score between 1 and 10 based on this arbitrary scale. The scores for the 4 responses were totaled to yield a total score.

Response Surface Methodology

Response surface methodology, as described by Davies (34), Cochran and Cox (35), Myers (36), and Henika (39), was used to investigate several baking responses to a number of different formula and process variations. The equation for responses of 3 independent variable experiments was :

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3$$

The equation for responses of 4 independent variable experiments was:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{44}X_4^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{34}X_3X_4$$

The RSM design for the 3 and 4 variable experiments is given in Table II and Table III respectively. The B values and associated statistics were estimated by using the SAS GLM computer program for multiple regression (45). This procedure solves the normal equation X'XB=X'Y using a modified sweep routine and produces a generalized inverse (X'X) and a solution $b=(X'X)^{-1}X'Y$. Tests of the hypothesis LB=0 are then made by computing $SS\ (LB=0) = (Lb)'(L(X'X)^{-}L')^{-1}(Lb)$, where Lb is a matrix of B estimators. The associated F values are computed using error mean squares. This program also provides the multiple correlation coefficient (R^2) for each response. R^2 is defined as the sum of squares attributable to regression divided by the correlated total sum of squares.

Surfactants

Four surfactants were used; SSL supplied by PATCO, EMG supplied by PATCO, Polysorbate (Tween 60) supplied by ICI America Inc., and SMG supplied by Eastman Kodak. Standard baking procedures were used, and the surfactants were added singularly and in combination at the .25% and .5% levels based on flour weight. In the cases where surfactants were added in combination, the total of all the surfactants was the same (.25% or .50%) as was that of the single surfactant additions for that experiment. The design for the surfactant mixture experiments at .25% and .50% surfactant levels is outlined in Table IV and Table V respectively.

Table II. RSM Design for Three Processing Variables at Five Levels

Number sequence	Variables		
	X_1	X_2	X_3
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-1.682	0	0
10	1.682	0	0
11	0	-1.682	0
12	0	1.682	0
13	0	0	-1.682
14	0	0	1.682
15-20	0	0	0

X_1 = Yeast level, -1.682=3.5 gms., -1 = 4.5 gms., 0=6.0 gms., 1=7.5 gms., 1.682=8.5 gms.

X_2 = Fermentation time, -1.682=33 min., -1=40 min., 0=50 min., 1=60 min., 1.682=67 min.

X_3 = Proof time, -1.682=52 min., -1=55 min., 0=60 min., 1=65 min., 1.682=68 min.

Table III. RSM Design for Four Processing Variables at Five Levels

Number sequence	Variables			
	X_1	X_2	X_3	X_4
1	-1	-1	-1	-1
2	1	-1	-1	-1
3	-1	1	-1	-1
4	1	1	-1	-1
5	-1	-1	1	-1
6	1	-1	1	-1
7	-1	1	1	-1
8	1	1	1	-1
9	-1	-1	-1	1
10	1	-1	-1	1
11	-1	1	-1	1
12	1	1	-1	1
13	-1	-1	1	1
14	1	-1	1	1
15	-1	1	1	1
16	1	1	1	1
17	-2	0	0	0
18	2	0	0	0
19	0	-2	0	0
20	0	2	0	0
21	0	0	-2	0
22	0	0	2	0
23	0	0	0	-2
24	0	0	0	2
25-31	0	0	0	0

X_1 = Water, -2=87 ml, -1=90 ml, 0=93 ml, 1=96 ml, 2=99 ml.

X_2 = Mix, -2=4.5 min, -1=5.0 min, 0=5.5 min, 1=6.0 min, 2=6.5min.

X_3 = Gluten, -2=0.0 gms, -1=3.75 gms, 0=7.5 gms, 1=11.25 gms, 2=15.0 gms.

X_4 = Potasium bromate, -2=0.0 ppm, -1=20 ppm, 0=40 ppm, 1=60 ppm, 2=80 ppm.

Table IV. Experimental Design for .25% Surfactant Series

Number of repetition	SSL g.	EMG g.	Polysorbate 60 g.	SMG g.
3	.375	0	0	0
3	0	.375	0	0
3	0	0	.375	0
3	0	0	0	.375
2	.1875	.1875	0	0
2	.1875	0	.1875	0
2	.1875	0	0	.1875
2	0	.1875	.1875	0
2	0	.1875	0	.1875
2	0	0	.1875	.1875
2	.234	.047	.047	.047
2	.047	.234	.047	.047
2	.047	.047	.234	.047
2	.047	.047	.047	.234

Table V. Experimental Design for 0.5% Surfactant Series

Number of repetitions	SSL g.	EMG g.	Polysorbate g.	SMG g.
3	.75	0	0	0
3	0	.75	0	0
3	0	0	.75	0
3	0	0	0	.75
2	.375	.375	0	0
2	.375	0	.375	0
2	.375	0	0	.375
2	0	.375	.375	0
2	0	.375	0	.375
2	0	0	.375	.375
2	.469	.094	.094	.094
2	.094	.469	.094	.094
2	.094	.094	.469	.094
2	.094	.094	.094	.469

The analysis was done by utilizing a surface response model similar to RSM techniques, but the independent variables are defined such that the sum $X_1 + X_2 + X_3 + X_4 = C$ where C must be a constant which was defined as .25% or .50% of flour weight for this experiment. The equation for the response model was:

$$Y = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{34}X_3X_4.$$

The independent variables (X_1, X_2, X_3, X_4) are the levels in grams of SSL, EMG, Polysorbate (Poly) and SMG respectively. The B values and associated data were estimated by using the SAS GLM computer program for multiple regression (45) in a similar manner to that used in the RSM analysis.

Design and Analysis of Sensory Test

There are numerous different experimental designs and statistical analysis for sensory evaluation of food products (46,47,48). A ranking preference design was used for this experiment (48), where the subject was asked to taste two samples identified by a random 3-digit number, one of which was a conventionally baked bun and the second a conventionally browned and microwave baked bun. He was asked to indicate how well he likes or dislikes each on a scale of likes very much, likes, neither likes or dislikes, dislikes, and dislikes very much.

The samples were baked approximately 24 hours prior to evaluation. The bun was sliced and two cross-sections were placed in

plastic bags identified by a 3-digit number. The crust was not removed from the bun, but providing a sliced cross section would minimize the tendency of the subject to judge the bun on crust color difference alone.

Descriptive values were assigned numerical values from 1 to 5 with like very much given a value of 5 and dislikes very much a value of 1. Then an analysis of variance was done as outline by Larmond (48) and an F statistic computed. The Null hypothesis was tested to see if the response to the conventionally browned and microwave baked bun was significantly different from that of the conventionally baked bun. If the computed F value was less than the 5% points for the distribution of F (49), then the Null hypothesis was accepted, and there was no significant difference in acceptability between buns baked by the two baking procedures.

RESULTS AND DISCUSSION

Determination of Microwave Method

Initially a conventional control was established using the basic procedure outlined in Materials and Methods section by optimizing the water absorption, mix time, proof time, and oxidation. Fetty (5) and Decareau (9), both reported using microwave baking followed by conventional browning in the production of pan breads. This procedure was tried with buns. Various microwave bake times and intensities were tried followed by higher temperature, conventional browning. Conventional browning at 450°F was found to give a crust with satisfactory color and thickness and with a dramatic decrease in baking time. Various microwave baking times from 20 seconds to 120 seconds were used. Baking times over 60 seconds showed a very obvious firming of the crumb. When compressibility tests were done at 24 hours after baking, it was found that 50 second bake time produced a compressibility value comparable to the conventional control. If the microwave bake time was increased to 60 seconds the compressibility value was significantly higher than the control. If the microwave bake time was less than 40 seconds the crumb was obviously doughy and under baked. Therefore, 50 seconds was adopted as the optimum microwave bake time.

Reduction of proof time in microwave bread baking as was reported by Fetty (5) and Decareau (9), produced inferior volume when applied to the conditions used in this procedure.

Microwave bake times of 40 seconds or more produced a bun with a tendency to reach maximum volume before crumb was adequately baked to support the structure. Since there is no crust to support the structure, as in conventional bread, the bun would then shrink back in volume leaving a wrinkled appearances in the crust. Various combinations of conventional baking, both before and after microwave baking, were tried to see if partially or completely forming the crust before microwave baking would reduce the crust wrinkling problem.

Conventional baking for 4 1/2 minutes at 450°F before microwave baking was found to produce a crust that would support the crumb and virtually eliminated the problem of crust wrinkling. Microwave baking for 50 seconds at maximum intensity preceded by conventional browning for 4 1/2 minutes at 450°F was adopted as the standard conventional-microwave bake procedure. Reduction of proof time did not reduce wrinkling problem so the problem was not the result of excess proofing as might be suspected. Figure 1 shows examples of an optimum conventional bun, a bun baked with a microwave oven alone, a bun baked in a microwave oven before being browned in a conventional oven, and a bun browned in a conventional oven before being baked in a microwave oven.

RSM Formulation Series

Utilizing the conventional optimum as a center point, a 4 variable 5 level RSM experiment was designed as outlined in

Fig. 1. Bake procedures utilizing conventional and microwave methods both singularly and in combination.

Table III. The independent variables are water absorption (W), mix time (M), oxidation (B), and gluten (G). The fermentation time was 40 minutes, the proof time was 50 minutes, and both remained constant as defined in the materials and methods. The responses that were recorded were specific volume (SpV); compressibility at 1, 2, and 3 days (C_1, C_2, C_3); grain score; and total score. The sequence numbers were randomized and the experiment conducted in a random sequence. Experimental baking was completed in a maximum of 6 days to minimize yeast variability. The experiment was conducted for both the conventional bake procedure and the conventional-microwave bake procedure. The center points of the conventional RSM series were used as controls to verify consistency of yeast for the conventional-microwave baking series. The purpose of this experiment is to compare the optimum responses to absorption, oxidation, mix time, and gluten of these two baking systems. This will provide information as to potential differences in basic dough structure required by the two baking procedures.

The experimental results for the conventional bake series are given in Table VI, and the results for the conventional-microwave bake series are given in Table VII. These results were analyzed by computer using SAS GLM techniques (45), and the response equations for both conventional bake procedure and the conventional-microwave baking procedure are listed in Table VIII and Table IX respectively. Since the number of in-

Table VI. Effects of Processing Variables on the Quality of Buns Baked Conventionally

Bake	W ml.	M min.	G g	B ppm	SpV	Grain score	C 1 units	C 2 units	C 3 units	Total score
1	90	5.0	3.75	20	5.83	8	28	45	58	24
2	96	5.0	3.75	20	5.74	7	25	46	67	21
3	90	6.0	3.75	20	5.94	6	26	41	41	26
4	96	6.0	3.75	20	5.98	5	19	52	56	23
5	90	5.0	11.25	20	6.13	6	25	33	50	26
6	96	5.0	11.25	20	6.15	7	27	50	66	22
7	90	6.0	11.25	20	5.96	8	21	40	58	26
8	96	6.0	11.25	20	5.63	5	25	39	59	21
9	90	5.0	3.75	60	5.19	6	22	40	60	20
10	96	5.0	3.75	60	5.20	8	32	59	76	15
11	90	6.0	3.75	60	5.59	6	25	49	75	20
12	96	6.0	3.75	60	5.70	6	22	36	53	22
13	90	5.0	11.25	60	6.30	7	22	43	54	28
14	96	5.0	11.25	60	6.65	9	27	45	59	29
15	90	6.0	11.25	60	6.06	6	22	36	46	27
16	96	6.0	11.25	60	5.81	5	16	34	48	23
17	87	5.5	7.50	40	6.02	6	25	40	55	25
18	99	5.5	7.50	40	5.79	5	21	27	33	19
19	93	4.5	7.50	40	6.25	7	17	38	49	30
20	93	6.5	7.50	40	5.89	8	31	49	68	21
21	93	5.5	0.00	40	5.00	7	31	60	87	13
22	93	5.5	15.00	40	5.98	7	24	41	53	25
23	93	5.5	7.50	0	5.91	7	22	34	51	26
24	93	5.5	7.50	80	6.40	7	21	42	66	26
25	93	5.5	7.50	40	6.05	7	26	45	45	28
26	93	5.5	7.50	40	6.13	7	24	41	56	25
27	93	5.5	7.50	40	6.24	7	20	43	57	26
28	93	5.5	7.50	40	6.03	8	18	31	53	29
29	93	5.5	7.50	40	5.98	6	24	40	51	24
30	93	5.5	7.50	40	6.23	6	16	32	50	29
31	93	5.5	7.50	40	6.32	7	27	47	58	25

W=water level, M=mix time, G=gluten level, B=bromate, SpV=specific volume, C 1, C 2, C 3,=compressibility at 1, 2, 3 days, units=3.1 g.

Table VII. Effects of Processing Variables on the Quality of Buns Baked by Conventional-Microwave Process

Bake	W ml.	M min.	G g	B ppm	SpV	Grain score	C 1 units	C 2 units	C 3 units	Total score
1	90	5.0	3.75	20	4.68	7	44	74	90	14
2	96	5.0	3.75	20	4.17	6	68	84	81	8
3	90	6.0	3.75	20	5.36	6	33	57	58	24
4	96	6.0	3.75	20	4.71	7	42	90	90	15
5	90	5.0	11.25	20	5.71	8	28	34	52	29
6	96	5.0	11.25	20	5.04	6	22	37	53	27
7	90	6.0	11.25	20	5.36	7	39	55	61	22
8	96	6.0	11.25	20	5.49	7	23	60	63	27
9	90	5.0	3.75	60	4.22	7	48	53	90	11
10	96	5.0	3.75	60	4.19	7	52	90	90	9
11	90	6.0	3.75	60	5.23	7	39	53	73	19
12	96	6.0	3.75	60	3.97	6	70	90	90	6
13	90	5.0	11.25	60	5.55	5	31	41	57	23
14	96	5.0	11.25	60	5.16	7	33	55	61	23
15	90	6.0	11.25	60	5.28	6	34	52	66	22
16	96	6.0	11.25	60	5.04	5	23	45	59	24
17	87	5.5	7.50	40	5.20	7	43	62	82	17
18	99	5.5	7.50	40	4.16	6	48	67	75	11
19	93	4.5	7.50	40	5.00	8	35	62	82	19
20	93	6.5	7.50	40	5.33	6	30	61	71	22
21	93	5.5	0.00	40	4.20	7	60	83	90	10
22	93	5.5	15.00	40	5.29	6	30	58	62	24
23	93	5.5	7.50	0	5.24	4	30	56	69	20
24	93	5.5	7.50	80	5.20	8	31	65	71	23
25	93	5.5	7.50	40	5.28	8	25	57	56	28
26	93	5.5	7.50	40	5.12	7	37	53	75	20
27	93	5.5	7.50	40	5.12	8	35	54	62	23
28	93	5.5	7.50	40	5.00	7	34	52	65	23
29	93	5.5	7.50	40	5.53	7	34	59	66	24
30	93	5.5	7.50	40	5.08	8	29	50	60	26
31	93	5.5	7.50	40	5.20	6	30	52	49	27

W=water level, M=mix time, G=gluten level, B=bromate, SpV=specific volume, C 1, C 2, C 3,=compressibility at 1, 2, 3 days, units=3.1 g.

Table VIII. Response Surface Equations for the Conventional Bake Procedure

Dependent variable	Equation for response surface[a]
Specific volume	$Y= - 76.6592 + 1.4918X_1 - 4.4558X_2 + .8747X_3 - .0781X_4 - .0072X_1^2 - .03X_1X_2 - .0958X_2^2 - .0016X_1X_3 - .1007X_2X_3 - .012X_3^2 + .0006X_1X_4 + .001X_2X_4 + .0023X_3X_4$
Grain score	$Y= - 496.7560 + 9.4286X_1 + 28.9286X_2 + .3063X_3 - .5801X_4 - .0411X_1^2 - .375X_1X_2 + .5179X_2^2 - .0056X_1X_3 + .0333X_2X_3 + .0003X_3^2 + .0073X_1X_4 - .0188X_2X_4 + .0008X_3X_4$
Compressibility Day 1	$Y= - 194.4107 + .6964X_1 + 81.4881X_2 - 5.04X_3 - .7324X_4 + .0238X_1^2 - 1.0833X_1X_2 + 1.8571X_2^2 + .0444X_1X_3 - .0667X_2X_3 + .0952X_3^2 + .0104X_1X_4 - .025X_2X_4 - .0117X_3X_4 - .0004X_4^2$
Compressibility Day 2	$Y= - 2158.6726 + 38.4425X_1 + 127.5119X_2 - 1.0825X_3 + 3.2512X_4 - .1465X_1^2 - 1.8333X_1X_2 + 4.7262X_2^2 - .0111X_1X_3 - .3333X_2X_4 + .2085X_3^2 - .0229X_1X_4 - .1875X_2X_4 - .0033X_3X_4 - .0005X_4^2$
Compressibility Day 3	$Y= - 3032.9226 + 58.1786X_1 + 124.9286X_2 - 9.9937X_3 + 4.1095X_4 - .2437X_1^2 - 2.0833X_1X_2 + 5.7262X_2^2 + .0333X_1X_3 + .6X_2X_3 + .3062X_3^2 .0417X_1X_4 - .0567X_3X_4 + .0036X_4^2$
Total score	$Y= - 1011.3095 + 22.0357X_1 + 10.7857X_2 + 6.6635X_3 - .9381X_4 - .1235X_1^2 + .0417X_1X_2 - .9464X_2^2 - .0167X_1X_3 - .6333X_1X_3 - .1324X_3^2 + .0094X_1X_4 - .0188X_2X_4 + .0242X_3X_4 - .0003X_4^2$

[a] X_1= Water absorption, X_2= Mix time, X_3= Gluten level, X_4= Oxidation

Table IX. Response Surface Equations for the Conventional-Microwave Bake Procedure

Dependent variable	Equation for response surface[a]
Specific volume	$Y = -122.6733 + 2.6208X_1 + 2.9867X_2 - .053X_3 + .0429X_4 - .0142X_1^2 - .0175X_1X_2 - .0325X_2^2 + .0071X_1X_3 - .0767X_2X_3 - .008X_3^2 - .0002X_1X_4 - .0057X_2X_4 + .0006X_3X_4$
Grain score	$Y = -180.7798 + 3.9206X_1 + 3.1429X_2 + .3651X_3 - .0148X_4 - .0218X_1^2 - .2857X_2^2 - .014X_3^2 + .0021X_1X_4 - .0125X_2X_4 - .005X_3X_4 - .0008X_4^2$
Compressibility Day 1	$Y = 2961.875 - 66.3056X_1 + 12.5X_2 + 39.4222X_3 - 2.1875X_4 + .3924X_1^2 - .4583X_1X_2 + 1.125X_2^2 - .55X_1X_3 + 1.1X_2X_3 + .2422X_3^2 + .0156X_1X_4 + .1688X_2X_4 - .0108X_3X_4 - .0005X_4^2$
Compressibility Day 2	$Y = 1875.744 - 38.4464X_1 - 76.3214X_2 + 34.8619X_3 - 2.1676X_4 + .2285X_1^2 + .1667X_1X_2 + 5.2262X_2^2 - .5667X_1X_3 + 1.8667X_2X_3 + .2529X_3^2 + .0313X_1X_4 - .2X_2X_4 + .0217X_3X_4 + .0026X_4^2$
Compressibility Day 3	$Y = 4632.1697 - 79.3909X_1 - 332.9881X_2 + 3.173X_3 + 1.2574X_4 + .3812X_1^2 + 2.0X_1X_2 + 11.7262X_2^2 - .2222X_1X_3 + 2.2X_2X_3 + .1996X_3^2 - .0125X_1X_4 - .0375X_2X_4 - .0083X_3X_4 + .0033X_4^2$
Total score	$Y = -2475.9821 + 50.7282X_1 + 67.7976X_2 - 9.6857X_3 + .3256X_4 - .277X_1^2 - .2083X_1X_2 - 3.4702X_2^2 + .1944X_1X_3 - .9667X_1X_3 - .1239X_3^2 - .0010X_1X_4 - .0313X_2X_4 + .0025X_3X_4 - .0015X_4^2$

[a] X_1 = Water absorption, X_2 = Mix time, X_3 = Gluten level, X_4 = Oxidation

dependent variables was too large to represent relationships with contour plots, manual search procedures were used to find optimum regions for each response. This was done by utilizing the computer to generate, from the response surface, the estimated responses for various combinations of the independent variables covering the entire range of levels experimentally tested. These responses were visually inspected to determine which combinations of water absorption, mix time, gluten, and oxidation gave the best responses. The optimum regions are listed in Table X.

Comparison of the optimum regions of the two bake procedures shows that the optimum regions for water absorption, mix time, and gluten are either identical or overlapping for all responses. This would indicate that there is little if any difference in the response of the two baking systems to water absorption, mix time, and gluten level. Other than specific volume the responses to oxidation were optimum at lower levels with the conventional-microwave baking procedure than with conventional. Since the conventional-microwave procedure has lower volumes, the tougher crumb would be more apparent in the compressibility measurements.

Comparison of the optimum responses of the two systems shows that the conventional-microwave procedure produced buns with much smaller specific volume and with lower total scores than the conventional method, but with comparable compressibility values to the conventional procedure. Grain scores cannot be

Table X. Comparison of the Optimum Processing Regions for the Conventional and Conventional-Microwave Bake Procedures

Bake	Dependent variable	Optimum regions				Optimum responses	R^2
		Water %	Mix min	Gluten %	Bromate ppm		
Conv	SpV,cc	62-64	4.5-5.0	7.5-10.0	60-80	6.9-7.3	.879
Conv-MW	SpV,cc	60-64	4.5-5.0	8.5-10.0	60-80	5.7-5.9	.874
Conv	Grain score	62-66	4.5	7.5-10.0	60-80	9-10	.567
Conv-MW	Grain score	60-62	4.5-5.0	6.0-7.5	40-60	7-7.4	.368
Conv	C 1. unit	62	5.0	6.0-10.0	60-80	20-22	.317
Conv-MW	C 1. unit	62-64	4.5-5.0	8.5-10.0	60-80	16-20	.832
Conv	C 2. unit	62-66	5.0	6.0-8.0	40-80	40-42	.532
Conv-MW	C 2. unit	62-64	4.5-5.0	7.5-10.0	40-60	30-40	.611
Conv	C 3. unit	64-66	5.0	7.5-10.0	80	41-50	.585
Conv-MW	C 3. unit	62-66	4.5-5.0	8.0-10.0	40-60	50-55	.769
Conv	Total score	62-64	4.5-5.0	8.5-10.0	80	33-35	.814
Conv-MW	Total score	62-64	4.5-5.0	8.5-10.0	40-60	28-30	.859
Conv	Overall Optimum	64	4.5-5.0	7.5-10.0	80	-	-
Conv-MW	Overall Optimum	62-64	4.5-5.0	7.5-10.0	60	-	-

compared since the high values estimated for conventional bakes were not achieved experimentally. Pictures of buns from the optimum regions are provided in Figure II.

Since many of the combinations which produced optimums were at the ± 2 extremes of the gluten and oxidation ranges and were not tested experimentally in the RSM design, these combinations were verified experimentally. For the conventional procedure the maximum specific volume attainable without unacceptable reduction in grain score was 6.74. Grain scores ranged from 6-8. RSM compressibility estimations were consistent with experimental results. For the conventional-microwave procedure maximum specific volumes were attainable, but grain quality tended to decrease. Estimated compressibility values at one and two days were lower than those achieved experimentally. Estimated grain scores were comparable to experimental results except in cases where the volumes were the highest.

RSM Yeast, Fermentation and Proof Series

In an attempt to improve the quality, specifically volume of the conventional-microwave bun, an RSM series was designed as outlined in Table II. The independent variables for this series were proof time (R), fermentation time (F), and yeast level (Y). The measured responses were specific volume (SpV); grain score; compressibility at 1, 2, and 3 days (C_1, C_2, C_3); and total score.

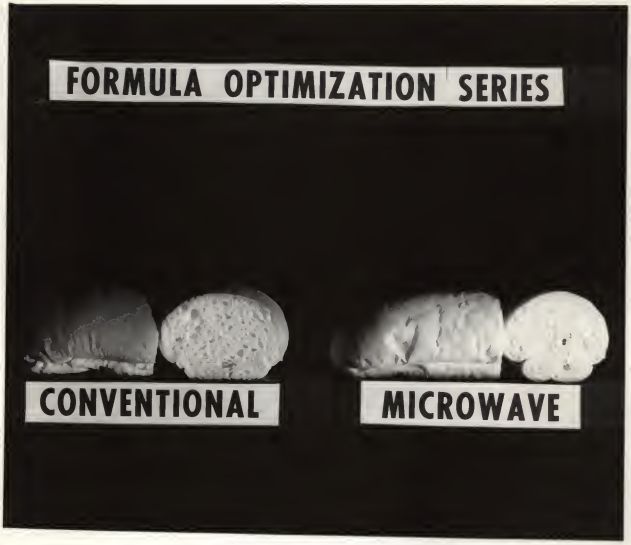

Fig. 2. Comparison of the formulation series optimums for the conventional bake method and the conventional-microwave bake method.

This experiment was first performed using the water absorption, mix time, gluten, and oxidation levels from the optimum ranges found in the conventional-microwave formulation series. Specific volumes increased dramatically, but grain scores decreased just as dramatically as large holes appeared in the crumb. This can be explained by the lack of extensibility that is present in a high protein, highly oxidized dough. Since the dough lacks extensibility it is unable to stretch and expand in the rapid fashion that is required with the increased proof rate with the conventional-microwave bake procedure. Therefore, the gluten films break allowing air cells to coalesce forming air pockets. There were also frequent problems of dough seams splitting during proofing. This also was caused by lack of extensibility.

Reducing gluten levels to 5% based on flour eliminated the problem of open grain even with increased yeast and proof levels. The RSM yeast, fermentation, and proof series was then repeated with both 5% gluten addition and with no gluten addition. The optimum levels for the other independent variables at 0% and 5.0% gluten levels from the RSM Formulation Series were used as a standard for this experiment. These levels were 60% water absorption, 5.5 minutes mix time and 20 ppm bromate for the 5.0% gluten level and 60% water absorption, 6.0 minutes mix time, and 20 ppm bromate for the 0.0% gluten level.

Preliminary tests using these conditions showed that at the 5% gluten level, there was a tendency for the crust to break

late in the conventional browning phase due to internal pressure. This break allowed sudden expansion of the dough in the area of the break causing formation of a single large hole. This problem was solved by reducing oven temperature for 5% gluten level to 430°F and increasing baking time by 20 seconds to 4 minutes 50 seconds. This allowed more dough expansion before setting of the crust. Since this problem did not exist without addition of gluten and since the reduction in gluten protein caused reduced crust color, the time and temperature was not altered for the 0.0% gluten series, and the standard procedure with 450°F for 4 1/2 minutes was used.

These experiments were each conducted in a randomized sequence in less than 6 days to reduce yeast variability. Controls from 5.0% gluten series were repeated during the 0.0% gluten series to verify consistency of the yeast performance. The results for the RSM yeast, fermentation, and proof series at 0.0% and 5.0% gluten levels are given in Table XI and Table XII respectively. These results were analyzed as in the formulation series using SAS GLM techniques (45), and the response equations are listed by response in Table XIII and Table XIV. Numerical search procedures were used in the same manner as was described with the RSM formulation series to determine the levels of independent variables that gave responses in the optimum regions. The optimum regions are listed by response in Table XV. Since the optimum regions of the independent variables for each response are either

Table XI. Effects of Yeast Level, Fermentation Time, and Proof Time on the Quality of Buns Baked by the Conventional-Microwave Procedure

Bake	Y g	F min	R min	SpV cc	Grain score	C1 units	C2 units	C3 units	Total score
1	4.5	40	55	4.65	7	45	55	87	9
2	7.5	40	55	5.58	6	34	53	52	20
3	4.5	60	55	4.95	6	56	69	80	6
4	7.5	60	55	6.27	7	28	32	53	26
5	4.5	40	65	5.43	7	40	66	90	13
6	7.5	40	65	6.09	7	32	51	65	22
7	4.5	60	65	5.31	7	36	70	70	16
8	7.5	60	65	6.58	6	27	32	44	28
9	3.5	50	60	4.49	6	44	83	90	8
10	8.5	50	60	6.30	7	28	43	50	27
11	6.0	33	60	5.67	8	36	58	73	18
12	6.0	67	60	5.74	8	36	49	60	19
13	6.0	50	52	4.88	6	32	50	89	11
14	6.0	50	68	6.15	7	28	49	68	22
15	6.0	50	60	5.51	6	32	61	86	14
16	6.0	50	60	5.50	7	31	52	84	15
17	6.0	50	60	5.66	6	26	40	56	22
18	6.0	50	60	5.56	7	30	60	56	21
19	6.0	50	60	5.56	7	32	61	54	21
20	6.0	50	60	5.84	6	30	54	72	19

Y=yeast level, F=fermentation time, R=proof time, SpV=specific volume. C1,C2,C3=Compressibility at 1,2,3 days, units=3.1 g.

Table XII. Effects of Yeast Levels, Fermentation Time, and Proof Time on the Quality of Buns Fortified with 5% Gluten and Baked by the Conventional-Microwave Procedure

Bake	Y g	F min	R min	SpV c c	Grain score	C1 units	C2 units	C3 units	Total score
1	4.5	40	55	5.04	7	37	49	65	16
2	7.5	40	55	6.00	7	24	43	55	26
3	4.5	60	55	5.08	6	35	54	53	17
4	7.5	60	55	6.36	6	34	47	57	23
5	4.5	40	65	5.42	6	25	48	50	23
6	7.5	40	65	6.65	7	18	33	34	35
7	4.5	60	65	5.96	7	24	57	55	25
8	7.5	60	65	7.03	7	19	31	42	33
9	3.5	50	60	4.73	7	64	90	90	7
10	8.5	50	60	6.85	7	22	39	42	33
11	6.0	33	60	5.56	7	30	37	48	23
12	6.0	67	60	6.32	4	25	36	65	21
13	6.0	50	52	5.53	7	35	41	43	22
14	6.0	50	68	6.57	7	27	34	40	30
15	6.0	50	60	6.05	7	28	48	50	26
16	6.0	50	60	5.93	7	26	44	48	26
17	6.0	50	60	6.03	7	25	45	61	24
18	6.0	50	60	6.27	8	27	50	56	26
19	6.0	50	60	5.92	5	29	35	47	23
20	6.0	50	60	6.16	7	27	42	39	28

Y=yeast level, F-fermentation time, R=proof time, SpV=specific volume. C1.C2.C3= Compressibility at 1.2.3 days. Units=3.1 gms.

Table XIII. Response Surface Equations for Yeast, Fermentation, and Proof Series without Gluten Fortification

Dependent Variable	Equation for Response Surface[a]
Specific volume	$Y=-6.6672 + .57X_1 + .0034X_2 + .2439X_3 - .0261X_1^2 + .0083X_1X_2 + .0005X_2^2 - .0016X_2X_3 - .0053X_1X_3 - .0006X_3^2$
Grain score	$Y=-11.3516 + 1.0691X_1 - .3476X_2 + .7416X_3 - .0378X_1^2 + .0083X_1X_2 + .0044X_2^2 - .0025X_2X_3 - .0167X_1X_3 + .0040X_3^2$
Compressibility Day 1	$Y= 279.6188 - 33.249X_1 + .3471X_2 - 4.3292X_3 + 1.2236X_1^2 - .15X_1X_2 + .0262X_2^2 + .035X_2X_3 + .3667X_1X_3 + .028X_3^2$
Compressibility Day 2	$Y= - 512.3799 + 16.3692X_1 + 4.5816X_2 + 14.3273X_3 + 1.1662X_1^2 - .4883X_1X_2 - .0075X_2^2 - .02X_2X_3 - .2333X_1X_3 - .0983X_3^2$
Compressibility Day 3	$Y= 380.6215 - 21.2152X_1 + 5.8522X_2 - 11.3089X_3 - .1281X_1^2 + .0583X_1X_2 - .0145X_2^2 - .0875X_2X_3 + .1833X_1X_3 + .1169X_3^2$
Total score	$Y= -151.5558 + 11.1738X_1 - 1.3744X_2 + 4.6647X_3 - .1715X_1^2 + .1X_1X_2 - .0003X_2^2 + .015X_2X_3 - .1667X_1X_3 - .0323X_3^2$

[a] X_1= Yeast level, X_2= Fermentation time, X_3= Proof time

Table XIV. Response Surface Equations for Yeast, Fermentation, and Proof Series with 5% Gluten Fortification

Dependent Variable	Equation for Response Surface[a]
Specific volume	$Y= 1.4759 + .7599X_1 - .0305X_2 - .018X_3 - .0408X_1^2 + .0013X_1X_2 - .0004X_2^2 + .0013X_2X_3 + .001X_1X_3$
Grain score	$Y= 38.3569 - 1.0012X_1 - .0085X_2 - .9271X_3 + .0389X_1^2 - .0083X_1X_2 - .0044X_2^2 + .0075X_2X_3 + .0167X_1X_3 + .0039X_3^2$
Compressibility Day 1	$Y= 80.8538 - 34.6575X_1 + 1.821X_2 + 1.5064X_3 + 1.8419X_1^2 + .1667X_1X_2 - .0132X_2^2 - .02X_2X_3 + .0333X_1X_3 - .0131X_3^2$
Compressibility Day 2	$Y= -457.9182 - 12.0512X_1 + 3.7979X_2 + 15.9062X_3 + 3.1846X_1^2 - .1X_1X_2 - .0279X_2^2 - .005X_2X_3 - .4667X_1X_3 - .1116X_3^2$
Compressibility Day 3	$Y= -290.2063 - 16.3478X_1 - 5.6010X_2 + 18.8463X_3 + 2.2174X_1^2 + .1416X_1X_2 + .0153X_2^2 + .0575X_2X_3 - .3833X_1X_3 - .1687X_3^2$
Total Score	$Y= 46.8111 + 11.2131X_1 + .8232X_2 - 3.5923X_3 - .6648X_1^2 - .0667X_1X_2 - .0076X_2^2 + .005X_2X_3 + .0667X_1X_2 + .0305X_3^2$

[a] X_1= Yeast level, X_2= Fermentation time, X_3= Proof time

Table XV. Comparison of Responses of Yeast, Fermentation, and Proof Series with and without Gluten Fortification

Gluten %	Dependent variable	Optimum Region			Optimum responses	R^2
		Yeast g	Fermentation min	Proof min		
0.0	SpV cc	5.0-5.67	50-67	60-68	6.5-7.1	.955
5.0	SpV cc	5.0-5.67	50-67	65-68	7.1-7.3	.979
0.0	Grain score	2.3-5.67	33-67	52-68	7.5-8.5	.530
5.0	Grain score	2.3-5.67	33-55	52-68	7.5-7.8	.517
0.0	C 1 units	4.0-5.67	50-60	52-68	25-27	.886
5.0	C 1 units	4.0-5.67	33-67	65-68	14-20	.702
0.0	C 2 units	5.0-5.67	55-60	52-68	21-35	.877
5.0	C 2 units	4.0-5.67	33-67	65-68	21-28	.866
0.0	C 3 units	4.0-5.67	33-67	55-68	36-48	.707
5.0	C 3 units	4.0-5.67	33-55	65-68	25-40	.716
0.0	Total score	5.0-5.67	55-67	55-68	29-32	.902
5.0	Total score	5.0-5.67	40-67	65-68	34-40	.900
0.0	Overall optimum range	5.0-5.67	40-50	60-68		
5.0	Overall optimum range	5.0-5.67	40-55	65-68		

C 1,2,3= Compressibility at 1, 2, 3 days, Units= 3.1 gms.

identical or overlap for the 0.0% gluten and 5.0% gluten levels, we can conclude that both high and low protein flours respond in the same manner to increasing yeast and proof levels. Most responses show optimum values over a relatively large range of fermentation times indicating that in the conventional-microwave bake system fermentation time, within the range tested, has little effect on the bun quality.

A comparison of optimum responses without gluten fortification and with 5.0% gluten fortification is made in Table XVI. The values in parentheses represent experimental values in cases where experimental verification of the RSM estimated optimum response did not agree with the RSM estimate at the ± 2 levels of the experimental design. Comparison of the RSM responses of the 0.0% and 5.0% gluten proof series and of experimentally verified values in the cases where they disagree with the RSM estimate, shows virtually no difference in the quality of the buns produced at the two levels. Pictures of the optimums for both gluten levels are shown in Figure 3. This is rather remarkable considering the fact that without gluten the flour protein is only 10.5%, a relatively low protein flour, and with 5.0% gluten addition the flour protein is 13.5% protein which is relatively strong flour. In the conventional RSM series a reduction of 5% gluten or 3% total protein caused a very dramatic reduction in specific volume of the bun (0.7-0.8 cc). One can then conclude that when using the conventional-microwave bake system the protein quantity

Table XVI. Comparison of Responses from Optimum Regions of Formulation Series, Yeast, Fermentation, and Proof Series, and Experimental Verification of Extreme Optimums[a]

Response	Formulation series		Yeast, fermentation, and proof series Conv-MW	
	Conv.	Conv-MW	No gluten	5.0% gluten
Specific volume,cc	6.9-7.3 (6.7)	5.7-5.9	6.5-7.1 (6.9-7.3)	7.1-7.3
Grain score	9-10 (7-8)	7.0-7.4	7.5-8.5	7.5-7.8
Compressibility 1	20-22	16-20 (20-25)	25-27	14-20 (24-28)
Compressibility 2	40-42	30-40 (38-48)	21-35 (37-49)	21-28 (30-45)
Compressibility 3	41-50	50-55	36-48 (43-57)	25-40 (40-53)
Total score	33-35 (31)	23-25	29-32	34-40 (30-33)

[a] All values in parenthesis represent values in which experimental verification of optimums was different than that estimated by RSM. This occurs in the ± 2 levels of the independent variables.

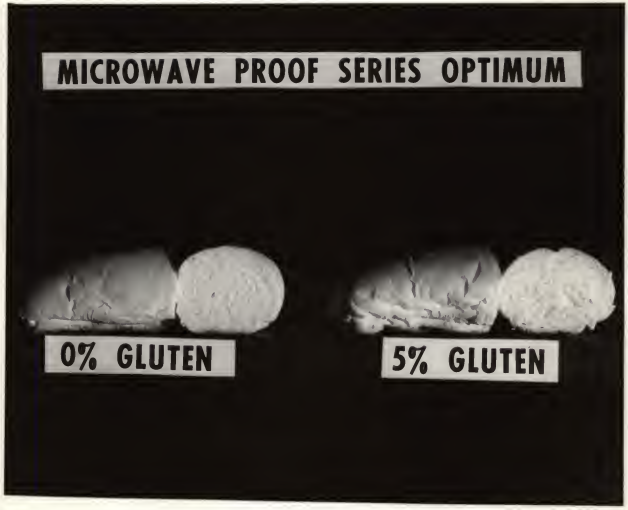

Fig. 3. Comparison of yeast, fermentation, and proof series optimums with no gluten fortification and with 5% gluten fortification.

is less critical than is generally the case with conventional bake systems, where a 3% reduction would greatly reduce the volume of the product. Chamberlain (6) reported that use of a conventional-microwave combined bake process allowed increasing the level of weak European wheat flour without loss of bread volume. He attributed this to a reduction of alpha-amylase activity during rapid baking since European wheat tends to have higher alpha-amylase content. However, his findings may be due, at least in part, to flour protein quantity being less critical in the conventional-microwave process as was found in the RSM yeast, fermentation, and proof series.

Table XVI also provides a comparison between optimum responses of the RSM formulation series and the RSM yeast, fermentation, and proof series. Basically this comparison shows that optimization of proof times and yeast levels greatly improved the buns baked by the conventional-microwave process. It also showed that the specific volumes, grain, compressibility at 2 and 3 days, and total scores obtained in conventional-microwave process were equivalent or better than those of the conventional control. Compressibility values at 1 day were slightly poorer with the conventional-microwave system than with the control.

Surfactant Series

The surfactant series were done using the standard method described in Methods and Materials with KSU Hipro flour. Both the

conventional and conventional-microwave baking processes were optimized. The conventional baking optimum was found to be 62% water absorption, 6.0 minutes mix time, 40 ppm potassium bromate, 50 minutes fermentation time, and 55 minutes proof time. The conventional-microwave baking optimum was found to be 62.0% water absorption, 6.0 minutes mix time, 0 ppm potassium bromate, 50 minutes fermentation time, and 60 minutes proof time.

The experimental results for the conventional surfactant series at the .25% and .50% levels are outlined in Table XVII and Table XVIII respectively. The results for the conventional-microwave series are outlined in Table XIX and Table XX respectively. The responses measured in the surfactant series were the same as in the RSM series, except the compressibility measurements were taken at 24±1 hours, 72±2 hours, and 120±2 hours to allow more time to observe antistaling properties of the surfactants. SAS GLM procedures (45) were used to analyze these results and to determine the response surface equations which are outlined in Tables XXI - XXIV.

The SAS GLM procedure provides a number of statistal values besides the response surface equation, such as analysis of variance, error mean square, standard error of estimate, and predicted values, which are used to determine which surfactants produce a significant improvement over the control at a .05 significance level. This was done by using the following procedure and equations:

Table XVII. Effects of .25% Surfactant Addition on the Quality of Buns Baked Conventionally

Bake	SSL g	EMG g	Poly g	SMG g	SpV c c	Grain score	C 1 units	C 3 units	C 5 units	Total score
33	.3750	0	0	0	6.54	7	14	40	57	34
34	.3750	0	0	0	7.01	6	16	38	52	34
35	.3750	0	0	0	6.71	5	12	36	47	33
36	0	.3750	0	0	5.81	7	16	43	57	29
37	0	.3750	0	0	6.07	6	16	42	58	29
38	0	.3750	0	0	6.12	6	15	45	59	29
39	0	0	.3750	0	6.20	6	16	45	56	30
40	0	0	.3750	0	6.56	6	14	34	61	34
41	0	0	.3750	0	6.30	7	18	45	59	31
42	0	0	0	.3750	5.82	7	18	46	57	28
43	0	0	0	.3750	6.02	6	16	41	54	29
44	0	0	0	.3750	6.24	6	17	31	56	32
45	.1875	.1875	0	0	6.67	8	17	31	46	36
46	.1875	.1875	0	0	6.85	7	15	36	47	35
47	.1875	0	.1875	0	6.68	7	14	30	79	36
48	.1875	0	.1875	0	6.80	7	13	34	53	37
49	.1875	0	0	.1875	6.90	7	15	38	52	35
50	.1875	0	0	.1875	6.77	6	12	41	50	33
51	0	.1875	.1875	0	5.81	7	21	50	57	27
52	0	.1875	.1875	0	6.01	7	24	40	65	29
53	0	.1875	0	.1875	6.12	6	16	42	59	29
54	0	.1875	0	.1875	6.20	7	20	51	68	28
55	0	0	.1875	.1875	6.17	8	16	43	62	31
56	0	0	.1875	.1875	6.06	7	16	39	66	31
57	.234	.047	.047	.047	6.73	6	12	33	49	35
58	.234	.047	.047	.047	6.96	7	13	42	55	35
59	.047	.234	.047	.047	6.19	6	12	39	54	31
60	.047	.234	.047	.047	6.23	6	16	44	54	32
61	.047	.047	.234	.047	6.32	5	12	40	52	31
62	.047	.047	.234	.047	5.54	6	15	38	47	32
63	.047	.047	.047	.234	6.72	4	14	42	50	31
64	.047	.047	.047	.234	6.21	7	16	43	58	31

SpV=specific volume, C 1, C 3, C 5=compressibility at day 1, 3, and 5.

Table XVIII. Effects of .50% Surfactant Addition on the Quality of Buns Baked Conventionally

Bake	SSL g	EMG g	POLY g	SMG g	SpV c c	Grain score	C 1 units	C 3 units	C 5 units	Total score
1	.750	0	0	0	6.79	6	12	34	42	34
2	.750	0	0	0	6.78	6	14	31	42	34
3	.750	0	0	0	6.67	8	13	39	46	34
4	0	.750	0	0	5.84	5	18	47	50	26
5	0	.750	0	0	5.51	6	19	54	64	22
6	0	.750	0	0	6.15	6	15	35	51	31
7	0	0	.750	0	5.81	8	16	41	63	30
8	0	0	.750	0	5.70	6	18	45	60	27
9	0	0	.750	0	5.80	6	15	35	59	30
10	0	0	0	.750	6.09	6	20	59	72	25
11	0	0	0	.750	6.08	7	16	37	59	31
12	0	0	0	.750	5.82	7	18	52	61	27
13	.375	.375	0	0	7.16	7	12	29	40	37
14	.375	.375	0	0	7.06	8	17	35	46	37
15	.375	0	.375	0	7.00	6	10	31	45	36
16	.375	0	.375	0	7.09	5	13	23	44	35
17	.375	0	0	.375	6.94	7	13	30	43	37
18	.375	0	0	.375	6.88	7	14	30	50	37
19	0	.375	.375	0	5.43	7	22	53	62	24
20	0	.375	.375	0	5.91	7	17	55	55	27
21	0	.375	0	.375	5.98	8	19	46	59	28
22	0	.375	0	.375	6.02	7	17	41	51	30
23	0	0	.375	.375	6.06	6	13	31	44	32
24	0	0	.375	.375	6.02	6	18	50	77	28
25	.469	.094	.094	.094	7.06	7	11	29	40	37
26	.469	.094	.094	.094	6.96	6	10	26	36	36
27	.094	.469	.094	.094	6.22	5	17	29	41	31
28	.094	.469	.094	.094	6.02	7	13	32	54	33
29	.094	.094	.469	.094	6.10	6	17	47	59	28
30	.094	.094	.469	.094	6.65	7	16	31	53	35
31	.094	.094	.094	.469	6.75	6	14	37	46	34
32	.094	.094	.094	.469	6.55	6	16	32	49	33

SpV=specific volume, C 1, C 3, C 5=compressibility at 1, 3, 5 days.

Table XIX. Effects of .25% Surfactant Addition on the Quality of Buns Baked by the Conventional-Microwave Procedure

Bake	SSL g	EMG g	POLY g	SMG g	SpV c c	Grain score	C 1 units	C 3 units	C 5 units	Total score
33	.375	0	0	0	6.65	7	20	43	45	31
34	.375	0	0	0	6.87	6	18	36	55	34
35	.375	0	0	0	6.78	7	24	37	50	32
36	0	.375	0	0	6.57	5	28	46	57	26
37	0	.375	0	0	5.92	5	25	53	55	23
38	0	.375	0	0	6.12	7	31	60	79	23
39	0	0	.375	0	6.11	7	29	51	63	25
40	0	0	.375	0	6.10	7	24	64	65	24
41	0	0	.375	0	6.52	7	27	29	60	26
42	0	0	0	.375	6.38	5	17	60	75	26
43	0	0	0	.375	6.27	7	30	62	64	24
44	0	0	0	.375	5.80	6	39	53	69	21
45	.1875	.1875	0	0	6.57	7	23	41	52	30
46	.1875	.1875	0	0	6.56	8	20	42	48	32
47	.1875	0	.1875	0	6.77	5	15	31	49	33
48	.1875	0	.1875	0	6.76	6	22	49	46	30
49	.1875	0	0	.1875	6.39	8	19	48	49	30
50	.1875	0	0	.1875	6.91	6	20	44	54	32
51	0	.1875	.1875	0	6.32	6	21	48	59	28
52	0	.1875	.1875	0	6.30	8	23	70	65	25
53	0	.1875	0	.1875	6.15	7	25	61	75	24
54	0	.1875	0	.1875	6.49	7	21	49	57	30
55	0	0	.1875	.1875	5.83	6	30	51	71	23
56	0	0	.1875	.1875	6.36	8	24	49	63	29
57	.234	.047	.047	.047	6.91	7	22	41	46	33
58	.234	.047	.047	.047	6.90	6	20	40	30	33
59	.047	.234	.047	.047	6.38	7	22	41	54	30
60	.047	.234	.047	.047	6.47	6	27	48	46	27
61	.047	.047	.234	.047	6.14	6	25	61	53	23
62	.047	.047	.234	.047	6.57	8	21	46	49	31
63	.047	.047	.047	.234	6.61	8	24	44	64	32
64	.047	.047	.047	.234	6.45	7	20	58	59	28

SpV=specific volume, C 1, C 3, C 5=compressibility at 1, 3, 5 days.

Table XX. Effects of .50% Surfactant Addition on the Quality of Buns Baked by the Conventional-Microwave Procedure

Bake	SSL g	EMG g	POLY g	SMG g	SpV c c	Grain score	C 1 units	C 2 units	C 3 units	Total score
1	.750	0	0	0	6.75	8	18	55	49	32
2	.750	0	0	0	6.76	8	24	41	60	32
3	.750	0	0	0	6.72	8	21	47	40	32
4	0	.750	0	0	6.32	7	19	54	56	28
5	0	.750	0	0	6.06	6	21	36	56	29
6	0	.750	0	0	6.42	6	18	52	44	29
7	0	0	.750	0	6.26	6	30	59	61	24
8	0	0	.750	0	5.85	6	27	70	43	20
9	0	0	.750	0	5.93	6	31	53	60	22
10	0	0	0	.750	6.60	7	19	46	42	30
11	0	0	0	.750	6.04	6	28	48	83	25
12	0	0	0	.750	6.17	7	23	48	62	27
13	.375	.375	0	0	7.16	8	14	27	44	38
14	.375	.375	0	0	6.92	6	17	63	39	34
15	.375	0	.375	0	7.18	7	14	38	42	36
16	.375	0	.375	0	7.15	7	13	38	36	36
17	.375	0	0	.375	6.75	8	17	32	48	36
18	.375	0	0	.375	6.44	9	19	42	56	33
19	0	.375	.375	0	6.46	6	26	56	49	26
20	0	.375	.375	0	5.99	6	31	47	63	23
21	0	.375	0	.375	6.40	6	22	42	55	30
22	0	.375	0	.375	6.42	8	24	53	62	29
23	0	0	.375	.375	6.39	4	29	48	48	24
24	0	0	.375	.375	5.94	6	33	70	63	19
25	.469	.094	.094	.094	7.06	7	18	31	40	36
26	.469	.094	.094	.094	6.89	7	15	32	39	36
27	.094	.469	.094	.094	6.77	5	18	38	56	32
28	.094	.469	.094	.094	6.15	5	22	40	55	28
29	.094	.094	.469	.094	6.56	5	17	48	40	29
30	.094	.094	.469	.094	6.81	7	29	46	45	29
31	.094	.094	.094	.469	6.61	7	18	29	52	35
32	.094	.094	.094	.469	6.61	7	18	39	55	34

SpV=specific volume, C 1, C 3, C 5=compressibility at day 1, 3, and 5.

Table XXI. Response Surface Equations for Buns Baked Conventionally with .25% Surfactant Addition

Dependent Variable	Equation for Response Surface[a]
Specific Volume	$Y= 18.0547X_1 + 16.0187X_2 + 16.8277X_3 + 16.1575X_4 + 10.444X_1X_2 + 3.4168X_1X_3 + 12.9251X_1X_4 - 9.7691X_2X_3 + 4.1481X_2X_4 - 3.5902X_3X_4$
Grain score	$Y= 16.2836X_1 + 17.3306X_2 + 16.7147X_3 + 16.8094X_4 + 30.7687X_1X_2 + 9.9232X_1X_3 - 3.28X_1X_4 + 6.8826X_2X_3 - 6.321X_2X_4 + 15.5005X_3X_4$
Compressibility Day 1	$Y= 38.0148X_1 + 41.5914X_2 + 42.6858X_3 + 46.2532X_4 - 6.9637X_1X_2 - 80.6060X_1X_3 - 85.1427X_1X_4 + 142.359X_2X_3 + 9.8223X_3X_4$
Compressibility Day 3	$Y= 101.797X_1 + 115.1374X_2 + 109.7083X_3 + 105.0373X_4 - 193.2177X_1X_2 - 208.4698X_1X_3 + 40.4299X_1X_4 + 75.975X_2X_3 + 154.2080X_2X_4 + 25.1781X_3X_4$
Compressibility Day 5	$Y= 140.8986X_1 + 156.3804X_2 + 154.4942X_3 + 149.6674X_4 - 301.4004X_1X_2 + 204.3889X_1X_3 - 145.4924X_1X_4 - 28.7383X_2X_3 + 119.1581X_2X_4 + .84.503X_3X_4$
Total score	$Y= 89.7116X_1 + 77.707X_2 + 84.2351X_3 + 79.0902X_4 + 119.377X_1X_2 + 103.6264X_1X_3 + 62.9868X_1X_4 - 67.0513X_2X_3 - 22.3576X_2X_4 + 4.5585X_3X_4$

[a] X_1 = SSL, X_2 = EMG, X_3 = Polysorbate 60, X_4 = SMG.

Table XXII. Response Surface Equations for Buns Baked Conventionally with .50% Surfactant Addition

Dependent Variable	Equation for Response Surface[a]
Specific volume	$Y= 8.9727X_1 + 7.738X_2 + 7.7061X_3 + 8.0406X_4 + 5.5703X_1X_2 + 5.6161X_1X_3 + 4.0233X_1X_4 - 1.0056X_2X_3 + .7083X_2X_4 + 1.5007X_3X_4$
Grain score	$Y= 8.9701X_1 + 7.4939X_2 + 9.0412X_3 + 8.8513X_4 + 7.4589X_1X_2 - 9.1673X_1X_3 + .4771X_1X_4 + 4.2872X_2X_3 + 6.8205X_2X_4 - 6.2502X_3X_4$
Compressibility Day 1	$Y= 17.1590X_1 + 22.9912X_2 + 22.2518X_3 + 24.0865X_4 - 10.5332X_1X_2 - 25.1176X_1X_3 - 18.9049X_1X_4 + 16.6561X_2X_3 - 2.0201X_2X_4 - 13.0489X_3X_4$
Compressibility Day 3	$Y= 47.0045X_1 + 59.3635X_2 + 54.9285X_3 + 66.0049X_4 - 75.5594X_1X_2 - 81.3395X_1X_3 - 96.9719X_1X_4 + 62.7179X_2X_3 - 48.9144X_2X_4 - 40.4723X_3X_4$
Compressibility Day 5	$Y= 57.7800X_1 + 73.5162X_2 + 82.0843X_3 + 84.8282X_4 - 56.6982X_1X_2 - 60.7358X_1X_3 - 67.5077X_1X_4 - 1.6907X_2X_3 - 47.5737X_2X_4 - 23.1669X_3X_4$
Total score	$Y= 45.070X_1 + 35.2130X_2 + 38.5712X_3 + 36.9983X_4 + 50.058X_1X_2 + 28.8486X_1X_3 + 45.3577X_1X_4 - 13.0395X_2X_3 + 17.6912X_2X_4 + 14.2601X_3X_4$

[a] X_1 = SSL, X_2 = EMG, X_3 = Polysorbate 60, X_4 = SMG.

Table XXIII. Response Surface Equations for Buns Baked by Conventional-Microwave Procedure with .25% Surfactant Addition

Dependent Variable	Equation for Response Surface[a]
Specific volume	$Y= 17.9894X_1 + 16.5099X_2 + 16.5886X_3 + 16.4248X_4 + 3.9796X_1X_2 + 8.7993X_1X_3 + 7.7704X_1X_4 + 2.8263X_2X_3 + 5.353X_2X_4 - 1.9163X_3X_4$
Grain score	$Y= 17.6542X_1 + 14.9397X_2 + 18.7486X_3 + 16.2236X_4 + 34.4179X_1X_2 - 38.7095X_1X_3 + 19.7024X_1X_4 + 17.6645X_2X_3 + 33.4098X_2X_4 + 17.1712X_3X_4$
Compressibility Day 1	$Y= 55.4410X_1 + 74.9687X_2 + 70.8754X_3 + 75.4517X_4 - 54.8843X_1X_2 - 127.0360X_1X_3 - 135.1768X_1X_4 - 132.0765X_2X_3 - 140.2173X_2X_4 - 13.2579X_3X_4$
Compressibility Day 3	$Y= 103.3884X_1 + 139.1223X_2 + 130.2879X_3 + 155.7322X_4 - 160.8835X_1X_2 - 84.0659X_1X_3 - 83.0627X_1X_4 + 225.7722X_2X_3 - 57.6691X_2X_4 - 80.407X_3X_4$
Compressibility Day 5	$Y= 132.8060X_1 + 169.7628X_2 + 167.7116X_3 + 188.0831X_4 - 303.3277X_1X_2 - 353.5989X_1X_3 - 306.7482X_1X_4 - 130.016X_2X_3 - 83.1653X_2X_4 - 33.8809X_3X_4$

[a] X_1 = SSL, X_2 = EMG, X_3 = Polysorbate 60, X_4 = SMG.

Table XXIV. Response Surface Equations for Buns Baked by Conventional-Microwave Procedure with .50% Surfactant Addition

Dependent Variable	Equation for Response Surface[a]
Specific Volume	$Y= 8.9768X_1 + 8.3196X_2 + 8.0423X_3 + 8.3764X_4 + 3.6824X_1X_2 + 5.7969X_1X_3 + .7876X_1X_4 + .6907X_2X_3 + 1.0503X_2X_4 + .5337X_3X_4$
Grain score	$Y= 10.6738X_1 + 8.2697X_2 + 8.1262X_3 + 9.0544X_4 - 4.0493X_1X_2 - 1.2466X_1X_3 + 7.2611X_1X_4 - 3.410X_2X_3 + 1.5426X_2X_4 - 9.8769X_3X_4$
Compressibility Day 1	$Y= 28.529X_1 + 26.0983X_2 + 39.2422X_3 + 30.6244X_4 - 36.4277X_1X_2 - 87.2236X_1X_3 - 37.2116X_1X_4 + 24.2482X_2X_3 + 3.1491X_2X_4 + 23.4643X_3X_4$
Compressibility Day 3	$Y= 63.8806X_1 + 63.7338X_2 + 82.1852X_3 + 62.8081X_4 - 43.3754X_1X_2 - 136.9389X_1X_3 - 105.2408X_1X_4 - 38.1538X_2X_3 - 27.7891X_2X_4 + 10.203X_2X_3$
Compressibility Day 5	$Y= 65.9185X_1 + 70.8388X_2 + 72.0613X_3 + 83.2716X_4 - 68.3629X_1X_2 - 108.1652X_1X_3 - 37.6682X_1X_4 + 14.1541X_2X_3 + 9.9845X_2X_4 - 33.3734X_3X_4$
Total score	$Y= 42.3042X_1 + 37.6636X_2 + 29.2813X_3 + 37.0177X_4 + 41.6689X_1X_2 + 68.0959X_1X_3 + 41.828X_1X_4 - 2.8845X_2X_3 + 17.0698X_2X_4 - 13.3921X_3X_4$

[a] X_1 = SSL, X_2 = EMG, X_3 = Polysorbate,60, X_4 = SMG.

equation 1: $(\text{Standard error of estimate})^2 = \frac{EMS}{C}$

equation 2: $Sp^2 = \frac{22\ (E.M.S.) + 5\ (S_2)^2}{27}$

equation 3: $t = \frac{\text{Estimate} - \text{Control}}{\sqrt{Sp^2\left(\frac{1}{C} + \frac{1}{6}\right)}}$

In the first equation the standard error of estimate and error mean square (EMS) are given by the SAS GLM printout and the constant C can be computed. In equation 2 a pooled variance $(Sp)^2$ is calculated using the EMS with 22 degrees of freedom and the control variance with 5 degrees of freedom. In equation 3 the t - test statistic is computed. The numerator is the difference between the predicted value from the GLM program and the mean of the 6 controls. The denominator terms were computed in equation 1 and 2. This t value was then used to test the null hypothesis; predicted value = mean of the control versus alternative hypothesis; predicted value is greater than the mean of the control. If the calculated t is greater than the t value from the t - distribution (49) at .05 significance level with 27 degrees of freedom, then we reject the null hypothesis and can say that this surfactant produced a significant improvement over the control without the surfactant. Table XXV summarizes by response and bake procedure the results of this test. SSL was the only surfactant that consistently showed significant improvement in the responses. At the .25% surfactant level SSL improved specific volume for both bake procedures.

Table XXV. Surfactants Showing Significant[a] Improvement over the Control

Bake Procedure	Level %	Response	Surfactant with Significant Improvement
Conventional	.25	SpV	SSL
		Grain score	None
		Compressibility 1	None
		Compressibility 3	None
		Compressibility 5	None
		Total score	SSL
Conventional	.5	SpV	SSL
		Grain score	None
		Compressibility 1	SSL
		Compressibility 3	None
		Compressibility 5	SSL
		Total score	SSL
Conventional-MW	.25	SpV	SSL
		Grain score	None
		Compressibility 1	None
		Compressibility 3	None
		Compressibility 5	None
		Total score	None
Conventional-MW	.5	SpV	SSL
		Grain score	SSL
		Compressibility 1	SSL+EMG+SMG
		Compressibility 3	None
		Compressibility 5	SSL
		Total score	SSL

[a] Surfactant when added individually showing significant improvement at the .05 significance level using t-test statistic.

At the .5% level SSL improved specific volume, grain, compressibility at day 1, compressibility at day 5, and total score for the conventional bake system, and it improved specific volume, compressibility at day 1, compressibility at day 5, and total score for the conventional-microwave series.

The SAS GLM procedure also provides information on quadratic interaction of 2 surfactants. The program gives an estimate of the effect of surfactant combinations and the probability that the quadratic interaction of two surfactants is significantly different than the planer relationship expected if the two surfactants blend linearly. In other words, if two surfactants have only a linear relationship when we replace, say, half of one surfactant by another keeping the total surfactant amount constant, we would expect the result of this combination to have a response that is approximately the average of the responses of the two surfactants when added singularly. However, when there is a significant quadratic component in the estimate there is some kind of interaction where, when two surfactants are added together we get a response that is quite different than the expected linear relationship. The surfactant combinations that show significant increases in response value at the .05% significance level are shown in Table XXVI and Table XXVII for the two bake procedures. All surfactant combinations that showed significant improvement included SSL. SSL has the capability to interact with some of the other surfactants and in some cases

Table XXVI. Comparison of Surfactants Added Singularly and in Combination [a] for the Conventional Bake Procedure

Level	Response	Surfactant	Predicted Value
Control	SpV	-	5.97
.25	SpV	SSL	6.77
.25	SpV	SSL+EMG	6.76
.25	SpV	SSL+SMG	6.87
.25	Grain score	None	-
.25	C 1	None	-
Control	C 3	-	44.8
.25	C 3	SSL+EMG	33.9
.25	C 3	SSL+Poly	32.3
Control	C 5	-	61.7
.25	C 5	SSL+EMG	45.1
Control	Total score	-	27.6
.25	Total score	SSL	33.6
.25	Total score	SSL+EMG	35.6
.25	Total score	SSL+Poly	36.3
.25	Total score	SSL+SMG	33.9
Control	SpV	-	5.97
.5	SpV	SSL	6.73
.5	SpV	SSL+EMG	7.05
.5	SpV	SSL+Poly	7.04
.5	SpV	SSL+SMG	6.95
.5	Grain score	None	-
Control	C 1	-	19.7
.5	C 1	SSL	12.9
.5	C 1	SSL+Poly	11.2
Control	C 3	-	44.8
.5	C 3	SSL+Poly	26.8
.5	C 3	SSL+SMG	28.7
Control	C 5	-	61.7
.5	C 5	SSL	43.3
Control	Total score	-	27.7
.5	Total score	SSL	33.8
.5	Total score	SSL+EMG	37.1
.5	Total score	SSL+Poly	35.4
.5	Total score	SSL+SMG	37.2

[a] Single surfactant additions that showed significant improvements above control in the response at the .05 significance level, and surfactant combination that showed a significant improvement or quadratic deviation from the linear response surface formed by individual surfactants.

Table XXVII. Comparison of Surfactants Added Singularly and in Combination for the Conventional-Microwave Bake Procedure[a]

Level %	Response	Surfactant	Predicted Value
Control	SpV	-	6.23
.25	SpV	SSL	6.75
.25	Grain score	None	-
.25	C 1	None	-
.25	C 3	None	-
Control	C 5	-	65.7
.25	C 5	SSL+Poly	43.9
.25	Total score	None	-
Control	SpV	-	6.23
.5	SpV	SSL	6.73
.5	SpV	SSL+EMG	7.00
.5	SpV	SSL+Poly	7.20
Control	Grain score	-	6.33
.5	Grain score	SSL	8.0
Control	C 1	-	30.0
.5	C 1	SSL	24.4
.5	C 1	EMG	19.6
.5	C 1	SMG	23.0
.5	C 1	SSL+Poly	15.4
.5	C 1	SSL+EMG	13.1
.5	C 1	SSL+SMG	15.9
Control	C 3	-	53.3
.5	C 3	SSL+Poly	35.5
.5	C 3	SSL+SMG	32.7
Control	C 5	-	65.7
.5	C 5	SSL	49.4
.5	C 5	SSL+Poly	36.5
Control	Total score	-	25.2
.5	Total score	SSL	31.7
.5	Total score	SSL+EMG	35.8
.5	Total score	SSL+Poly	36.4
.5	Total score	SSL+SMG	35.6

[a] Single surfactant additions that showed significant improvements above control in the response at the .05 significance level and surfactant combination that showed a significant improvement or quadratic deviation from the linear response surface formed by individual surfactants.

all of the other surfactants to produce response levels that were superior to that which is possible with either of the surfactants alone. Pictures representing quality improvements with SSL and SSL + Polysorbate at .5% level as compared to a control without surfactant are shown in Figure 4 for the conventional-microwave bake system. Quality improvements with SSL, SSL + EMG, SSL + Polysorbate, and SSL + SMG at .5% level are shown in Figure 5 for the conventional system.

Farinograms of doughs mixed with surfactants, both singularly and in combination with SSL, are outlined in Table XXVIII. When the surfactants were added at the .5% level singularly SSL showed a mix time that was 10-17 minutes greater than the other three surfactants, and a mixing tolerance that was 8-18 minutes greater than that found with the other surfactants. When the surfactants were combined with SSL at a total of .5% surfactant mix time increased to within 2-4.5 minutes of that of SSL alone. In combination the mixing tolerance was approximately the same or even higher than SSL alone. Farinograph peak heights were very similar for all the surfactants when added singularly, except SMG which was somewhat lower. In combination peak heights for SSL + SMG was somewhat lower than that for SSL + EMG or SSL + Polysorbate.

The mechanism of different surfactants in a dough system is very complex, and it would be very difficult to draw any conclusions concerning mechanism from the limited number of

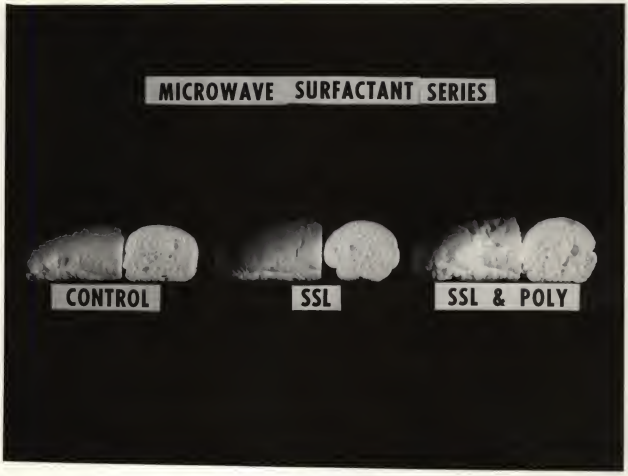

Fig. 4. Conventional-Microwave baked buns with 0.5% surfactants

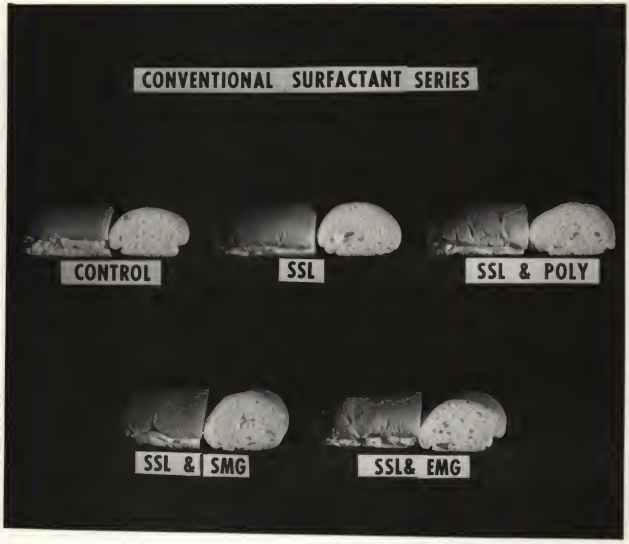

Fig. 5. Conventional baked buns with 0.5% surfactants

Table XXVIII. Effects of Surfactants on the Farinographic Properties of Dough[a]

Surfactant[b]	Peak Height B U	Mix Time min	Tolerance min
0	510	22.0	31.0
SSL	520	32.0	39.5
EMG	520	15.0	21.5
Polysorbate 60	520	22.0	30.0
SMG	490	22.0	31.0
SSL + EMG	510	28.0	38.0
SSL + Polysorbate 60	500	30.0	41.0
SSL + SMG	480	27.5	41.0

[a]All flours were adjusted to 14% moisture basis and received a constant water addition of 59.8% based on flour-weight.

[b]Surfactants when added individually were 0.5% of flour weight and when added in combination both surfactants were 0.25% of flour-weight.

experiments conducted. It would, however, be useful to discuss the results by comparing them with the known structures and properties of the surfactants from previously published research.

SSL has been reported to improve loaf volume, inhibit crumb firming (21), improve mixing tolerance (25), and decrease water absorption slightly (26). All of these characteristics were found to hold true in the baking and farinograph experiments that are represented here. EMG has been reported as having less binding capability than SSL and is linked significantly less to proteins and starch (26). This may account for SSL having a more significant improving effect than EMG when added alone. Dough stability is positively correlated with surfactant level for SSL but not for EMG, which is thought to indicate a difference in mechanism (26). SSL is thought to displace glycolipids, while EMG is thought to displace phosholipids (27). This may also indicate a difference in mechanism between the two surfactants. SSL is a anionic, hydrophilic surfactant and EMG is a nonionic, hydrophilic surfactant. Therefore, the hydrophilic group of SSL is capable of ionic bonding, while the hydrophilic group of EMG is capable of hydrogen bonding. All these differences may help explain why SSL produced more significant improvements than EMG. SSL and EMG in combination had a synergistic effect yielding dramatic improvement in the product quality. These potential differences in mechanism may help explain this interaction between SSL and EMG. Where SSL and EMG may have a different

mechanism they could function in a complimentary manner in the dough system. If both surfactants had the same mechanism, and we replaced half of one surfactant by another as was done in this experiment, the dramatic synergistic effect probably would not have been possible. This complimentary effect might be further explained in terms of the chemical structure of SSL and EMG. Both SSL and EMG possess a hydrophobic and a hydrophilic group as is characteristic of surfactants, but since SSL is anionic and EMG is polar nonionic they are not in direct competition for binding sites for their hydrophilic groups. SSL is capable of forming ionic bonds while EMG is capable only of hydrogen bonding. Since they bond at different hydrophilic sites they can work together in interactions between hydrophobic and hydrophilic phases in the dough system.

Polysorbate 60 is very similar to EMG in chemical structure, except it has one more -OH group capable of hydrogen bonding. Its lack of ability to provide a significant improvement in dough properties and final product quality when added alone is probably due to the same factors that were outlined in the discussion of EMG and SSL. The synergistic effects noted with SSL + EMG were also found with SSL + Polysorbate 60, but SSL + Polysorbate 60, overall, gave better responses than did SSL + EMG. This might be explained by the fact that Polysorbate 60 has three hydrogen bonding sites as compared to EMG which has only two. Polysorbate 60 would be capable of binding to more

hydrophilic substances than EMG, or it would be capable of forming a stronger bond with a substance with multiple hydrogen bonding sites.

SMG is an anionic, hydrophilic surfactant as is SSL. The degree of protein binding for SMG is less than that of SSL (28). SMG is also much more readily released by gluten when heated than SSL (28). This may indicate that SMG is bound to gluten protein to a lesser degree or that the existing bonds are not as strong. These differences in protein-surfactant bonding may explain why SSL had more significant improving effect than SMG when added singularly to the doughs. These differences may suggest a difference in mechanism between SSL and SMG even though their basic structure is similar. A difference in mechanism between SSL and SMG as with SSL + EMG and SSL + Polysorbate 60 may explain why SSL + SMG could have a synergistic effect when added in combination.

Comparing the responses of the surfactants, both singularly and in combination, of the two bake systems in Table XXVI and Table XXVII shows that there is little difference between the responses of the two systems. The surfactant combinations did show a significant improving effect at the .25% surfactant level more readily in the conventional bake system. Also at the .5% level SSL + Polysorbate 60 produced somewhat better specific volume than the other surfactant combinations in the conventional-microwave system. In the conventional system the specific volume response

was almost identical for SSL + EMG, SSL + Polysorbate 60 and SSL + SMG. These differences in specific volume response are probably due to the fact that the conventional-microwave requires more expansion of the dough during proofing and more rapid expansion of the dough during baking. If a surfactant combination such as SSL + Polysorbate 60 could yield a dough with superior ability to expand rapidly and retain gas, it would produce superior volume with the conventional-microwave system.

Analysis of Sensory Test

Two taste panels were conducted as outlined in Materials and Methods. A total of 101 panelists were asked to evaluate the acceptability of the conventional-microwave baked bun, as compared with the conventionally baked bun. The results of the test are outlined in Table XXIX. The analysis of variance for both taste panels is also presented in Table XXIX. The calculated F - Value for panel 1 of .3290 was less than the F - Value (5% significance level, 52 degrees of freedom) from the F distribution which was 4.02. The calculated F value for panel 2 of 3.4318 was also less than the F - value (5% significance level, 47 degrees of freedom) from the F distribution which was 4.04. Since for both taste panels the calculated F value was less than the test statistic from the F distribution, we must accept the null hypothesis that the acceptability of the conventionally browned-microwave baked bun is not significantly different from the conventionally baked bun.

Table XXIX. Evaluation of the Acceptibility of Conventional-Microwave Baked Buns by Taste Panels

Category	Taste Panel No. 1 No. Response		Taste Panel No. 2 No. Response	
	Conv.	Conv.-MW	Conv.	Conv.-MW
Like very much	16	11	15	6
Like	24	28	25	30
Neither Like or Dislike	8	11	4	6
Dislike	5	3	3	6
Dislike very much	0	0	1	0
Total	53	53	48	48

Analysis of variance for results from the evaluation of taste panel No. 1

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Sample	1	.1509	.1509	.3290
Panelist	52	53.3962	1.0268	2.2390
Error	52	23.8491	.4586	
Total	105	77.3962		

Analysis of variance for results from the evaluation of taste panel No. 2

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Sample	1	2.0416	2.0416	3.4318
Panelist	47	44.9583	.9566	1.6080
Error	47	27.9584	.5949	
Total	95	74.9583		

SUMMARY

An optimum conventional-microwave baking procedure for buns was developed from this study. It consisted of a conventional browning for 4 1/2 minutes at 450°F followed by 50 seconds microwave baking to produce products equal in quality to conventionally baked buns. The new procedure could reduce the conventional time to less than half.

Response Surface Methodology (RSM) was used to study the effect of water absorption, mix time, gluten level, and oxidation on the quality of buns baked by the conventional and conventional-microwave bake procedures. The optimum levels of these factors were found to be virtually the same in both baking procedures, but the optimum product produced by the conventional-microwave system was inferior in quality.

In attempt to improve the quality of the conventional-microwave baked bun, an RSM series was conducted to find the optimum yeast levels, fermentation time, and proof time. This series was conducted with no gluten fortification and with 5.0% gluten fortification. Increasing yeast level from 4.0 to 5.7% and increasing proof times from 50 to 60-68 minutes produced a bun of equal quality to that of the conventional control. Fermentation times between the range of 38-67 minutes had only a small effect on bun quality. There was virtually no difference in quality, including specific volume, between the optimum buns with 5.0%

gluten fortification and those without fortification. This is rather remarkable compared to the conventional bake system where specific volume and quality are effected very significantly by flour protein quality and quantity.

The response of both the conventional baking system and the conventional-microwave baking system to surfactant-additions was evaluated. Sodium stearoyl-2-lactylate (SSL), ethoxylated monoglycerides (EMG), polyoxythylene (20) sorbitan monostearate (Polysorbate 60), and succinylated monoglyceride (SMG) were added singularly and in combination at the .25% and .5% levels. The results were analyzed statistically. SSL was the only surfactant that, when added alone, consistently improved product quality in both bake systems. SSL in combination with EMG, Polysorbate 60, or SMG was capable of producing significant improvements in most responses measured, especially at the .5% surfactant level. Both the conventional procedure and the conventional-microwave procedure responded in a similar manner to the surfactant additions.

Taste panels with a total of 101 participants were asked to compare the acceptability of buns produced by the conventional-microwave bake process and by the conventional process. An analysis of variance on the panel results showed no significant difference in acceptibility of the two products.

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MICROWAVE BAKING OF YEAST RAISED DOUGHS

by

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B. S., Kansas State University, Manhattan, Kansas
1970

AN ABSTRACT OF A MASTERS
THESIS

Submitted in partial fullfillment of the
requirements for the degree

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in
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Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1979

Basic straight dough techniques were used to investigate the use of microwave baking in combination with conventional browning in production of hotdog buns. Conventional browning at elevated temperatures prior to microwave baking was found to produce superior products.

Response surface methodology was used to study several responses to variations in water absorption, mix time, gluten level, and oxidation. The conventional-microwave procedure produced lower volumes and lower quality buns than the conventional procedure but both systems were found to produce optimums over the same ranges of water absorption, mix time, gluten, and oxidation.

RSM techniques were also used to study the effects of yeast, proof time, and fermentation. Optimizing proof time and yeast levels produced a conventional-microwave product that was equal in quality to the conventionally baked product according to both measured responses and taste panels.

Addition of surfactants to doughs baked using both systems showed that their responses to the surfactants were virtually the same. It also showed that SSL was the only surfactant tested that significantly improved quality when added alone at .25% and .5% levels. SSL when combined with EMG, Polysorbate, or SMG showed a combined improvement that was significantly better than the expected linear relationship between the two surfactants when added singularly.

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